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WAWAITIN GS
WEST DYKE REHABILITATION
TEST RESULTS OF
ROLLER COMPACTED CONCRETE CORES

Report No 89-184-K

P.K. Mukherjee
Senior Engineer
Concrete Technology Section
Civil Research Department

ABSTRACT

A Roller Compacted Concrete (RCC) system was proposed for the rehabilitation of Wawaitin GS control dam. Prior to the implementation of the system, trial strips were laid with three different mixes of suitable consistency. Conventional earth moving equipment and vibratory rollers were used to spread and compact the layers of RCC. RCC core samples were obtained at various ages up to 6 months, and tests were carried out to determine physical properties. Although limited in scope, the test results are promising. Further work is required with job site materials to determine long-term durability properties.

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To: Mr. O. Bernaus
Manager
Civil Maintenance Department
Hydraulic Generation Group

Attn: Mr. R.T. Judek

WAWAITIN GS
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TEST RESULTS OF ROLLER COMPACTED CONCRETE CORES

1.0 INTRODUCTION

A report was submitted on the Roller Compacted Concrete (RCC) system proposed for the rehabilitation of Wawaitin GS control dam[1]. The report included details of a field trial carried out at the Dufferin Construction Co. yard at the Pearson International Airport, Toronto. Three trial strips of RCC pads were placed on October 29 and 30, 1987, using three types of concrete mixtures (see Figure 1 and Table 1). The placement technique and other site procedures have been described in the report cited above. A number of 150 mm diameter cores were drilled at various locations from the trial strips and were tested to determine the quality of the in-situ RCC. This report summarizes the results of these tests.

2.0 FIELD WORK

Sets of cores were drilled from the pads in December 1987 and April 1988. The general locations of the cores are shown in Figure 1. All these cores were wrapped in plastic sheets, after surface wiping. They were then kept at the laboratory temperature conditions until tested. Some of the cores, as received in the laboratory, are shown in Figure 2.

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1. Research Division Report No. 88-40-K, dated May 30, 1988.

As stated in the report cited earlier, a series of control cylinders was made by a special technique during placement of the trial pads. These cylinders were cured in the moist room at 23°C, 100% relative humidity until tested at various ages.

A summary of the various methods of compaction during placement and the corresponding density values measured by a nuclear density gauge and the values determined for the cores are shown in Table 2 and Figure 3. As well, the densities of the control cylinder are given.

3.0 TESTS AND RESULTS

The test results of the control cylinders up to the age of 6 months are given in Table 3. A series of tests was carried out on the cores at 6, 9 and 12 months. These tests are listed below. Also, reference is made to the corresponding tables and figures where the results of these tests are given. Appropriate CSA or ASTM test procedures were followed, where applicable. References to these procedures are included in the tables.

a) Compressive Strength, Ultrasonic Pulse Velocity, and Density: Table 4, Figure 4.

b) Splitting Tensile Strength, Ultrasonic Pulse Velocity, and Density: Table 5, Figure 5.

c) Apparent Specific Gravity, Absorption and Volume of Voids: Table 6.

d) Permeability by Chloride-Ion Diffusion Test: Table 7.

e) Shear Strength: Table 8, Figure 6 and 7.

f) Freeze-Thaw Resistance of a prism (400 x 75 x 100 mm) saw-cut from a core containing a one-day old joint: Table 9, Figures 8 and 9.

4.0 REMARKS

Based on the limited number of tests and evaluation of the results, the following remarks are made:

4.1 Under laboratory conditions, the control cylinders of all three mixes continued gaining strength during the 6-month curing period.

4.2 The values for density, ultrasonic pulse velocity and the compressive strength of the cores are comparable to those obtained on control cylinders at 91 days. Since the cores are from various locations and compacted by different methods, only the cores with known compaction methods have been compared in Figure 3. It appears that the in-situ RCC will continue to gain strength with time under moist conditions.

4.3 The water absorption values and the total void contents of the cores are not unusual, except for one test (Mix 2, pad 1) where test result values are higher than normal (Table 6).

4.4 The chloride-ion diffusion characteristics, which indirectly measures the permeability of the concrete, indicate that a wide variation can be expected. The values may range from high to very low according to the rating recommended by the Portland Cement Association (see Table 7). The values at a joint were generally higher than those obtained away from the joint. The value at the one-day old joint was the highest, indicating a high permeability at the joint.

4.5 The shear strength of the concrete at the day-old joint made with a sand-cement grout was similar to that of the concrete away from the joint (see Table 8), although, as noted in Section 4.4 above, the joint showed relatively high permeability.

4.6 The freeze-thaw (F/T) test on the saw-cut prism was carried out under saturated condition. It may be noted (see Table 9) that the specimen broke into two pieces at the joint between 44 and 64 cycles of F/T. At that time, the dynamic modulus dropped to about 64%. The pieces were kept under saturated conditions and were sealed in plastic bags without free water and continued to be subjected to F/T cycles. The weight loss and the change in ultrasonic pulse velocity (UPV) values were monitored up to 465 cycles. A loss of the surface material of the pieces continued to occur with a reduction in UPV, indicating a progressive loss of integrity of the concrete (see Figures 8 and 9). However, it should be noted that the pieces did not turn into rubble, as would be expected for a non-air-entrained conventional concrete made with 220 kg/m^3 of cement. The above observations are based on tests carried out on one test specimen only. Therefore, further work is needed to evaluate the F/T performance of the RCC.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Although limited in scope, the test results are promising in terms of the quality, field compaction method, strength and densities of the in-situ concrete.

5.2 Further work is required in order to optimize the mix proportions, using job-site materials and to improve the quality of the joints. Also, work is needed to investigate the freeze-thaw durability of roller compacted concrete.

Approved by:

T.W. Klym
Manager
Civil Research Department

Prepared by:

P.K. Mukherjee
Senior Engineer
Concrete Technology Section

Reviewed by:

G.S. Kellay
Supervising Engineer
Concrete Technology Section

PKM:amt:fc

Table 1
Actual Mix Proportions (kg/m^3)
(Average of 8 batches)

Material	Mix 1	Mix 2	Mix 3
Cement Type 10	220	202	99
Fly ash Type F	-	-	99
Granular 'A' Aggregate	2058	2057	1940
Water	144	139	135
Average cement factor Calculated from the yield	218	204	104

(CV13)

Table 2
Troxler Nuclear Density Gauge Readings at a Depth of 150 mm
with Various Compaction Methods and the Concrete Core Test Results (*)

Number of Passes and Compaction Method (See Remark 2)	Density of RCC by Troxler Gauge kg/m^3 Mix			Remarks
	1	2	3	
PAD 1, LIFT 1 (See Remark 1)				
2 Vib (8-3/4^t)	2219	2184	2185	1. The identification of pad and lift numbers are shown in Figure 1.
Additional 1 Vib + 1St (8-3/4^t)	2268	2205	2201	
Additional 4St (8-3/4^t)	2273	2230	2220	2. The number of passes and the compaction method are shown as below:
Core Density (kg/m^3)	2400	2430	2400	
Core Strength (MPa)	23.4	26.5	18.9	- 2 Vib (8-3/4^t) means two passes of 8-3/4 ton vibratory roller at 40,000 lb.
PAD 1, LIFT 2				
3 Vib + 5St (8-3/4^t)	2170	2151	2251	
Addtional 2St (8-3/4^t)	2177	2170	2240	- 1St (8-3/4^t) means one pass of 8-3/4 ton roller static (without vibration)
Core Density (kg/m^3)	2440	-	-	
Core Strength (MPa)	24.3	-	-	- 3LV (6^t) means three passes of 6 ton two steel drum roller with 9383 lb vibration/drum
PAD 2, LIFT 2				
4 Vib (8-3/4^t) + 2St (8-3/4^t)	2285	2272	2223	
Core Density (kg/m^3)	2430	2430	2410	- 2HV(6^t) means two passes of 6 ton two steel drum roller with 11858 lb vibration/drum
Core Strength (MPa)	22.2	25.4	15.9	
PAD 3, LIFT 2				- 2S (6^t) means two passes of 6 ton two steel drum roller 7357 lb static/drum
3LV + 2HV + 2S (6^t)	2201	2244	-	
(Except for Mix 3: 2LV + 4HV + 2S)	-	-	2256	
Core Density (kg/m^3)	2450	2460	2440	
Core Strength (MPa)	28.3	24.7	17.2	

(*) All cores were tested at 6 months

(CV13)

Table 3
Density, Ultrasonic Pulse Velocity (UPV) and
Compressive Strength Test Results For RCC Field Cylinders
(150 mm diameter x 300 mm)

RCC Mix	Specimen No.	Date Cast	After demoulding at 24 hours		Compressive Strength and UPV at Various Ages			
			Density (kg/m^3)	UPV (m/s)	Age (Days)	UPV (m/s)	Strength (PSI)	Strength (MPa)
1	13867-1	Oct.28	2301*	3960	7	4010	2025	14.0*
	-2	1987	2448	4175	28	4480	4245	29.3
	-3		2396	4175	28	4480	3866	26.7
	-4		2407	4235	91	4620	4070	28.1
	-5		2436	4235	91	4550	4070	28.1
	-6		2414	4235	180	4480	4530	31.2
2	13868-1	Oct.29	2403	4235	7	4290	3000	20.7
	-2	1987	2405	4295	28	4550	3885	26.8
	-3		2404	4235	28	4550	3950	27.2
	-4		2418	4295	91	4620	4266	29.4
	-5		2366	4295	91	4620	4200	28.9
	-6		2350	4295	180	4355	4860	33.5
3	13869-1	Oct.29	2370**	3670	7	3810	725	5.0
	-2	1987	2369	3765	28	4235	1935	13.3
	-3		2364	3720	28	4235	2040	14.1
	-4		2360	3720	91	4355	2560	17.6
	-5		2391	3720	91	4415	2978	20.5
	-6		2396	3720	180	4355	3790	26.1

(CV13)

\+ For mix proportions, see Table 1
* Low density due to partial compaction
** Voids between layers noted

Table 4
Test Results of 150 mm diameter Core Samples Obtained
from the RCC Trial Test Pads of Various Mixes

		Mix 1			Mix 2			Mix 3		
Pad No.	Age in Months	Density(*) kg/m^3	UPV(**) m/s	Compressive Strength MPa(+)	Density(*) kg/m^3	UPV(**) m/s	Compressive Strength MPa(+)	Density(*) kg/m^3	UPV(**) m/s	Compressive Strength MPa(+)
1	6	2440	4420	24.3	2440	4270	28.5	2400	4060	18.9
		2400	4150	23.4	2430	3610	26.5	2400	3880	19.0
2	6	2430	-	20.7	2430	4300	25.4	2410	3790	14.5
		2430	4070	22.2	2480	4360	23.7	2410	3840	15.9
3	6	2450	3860	28.3	2460	3950	24.7	2440	3950	17.2
		2460	3990	29.6	2460	3970	24.8	2440	3950	16.2
	9	2470	4490	28.1	2470	4390	21.0	2450	4170	17.5
		2470	4290	28.8	2480	4290	19.5	2450	4110	16.1
	12	2470	4650	34.5	2470	4360	22.8	2450	4250	23.7
		2470	4560	19.6(++)	2480	4480	25.3	2430	4040	21.8

(CV13)

(*) Determined, based on weights in air and water at room temperature

(**) UPV: Ultrasonic Pulse Velocity (ASTM C 597)

(+) Compressive Strength Test: CSA/CAN-A23.2-10C, length to diameter ratio 2

(++) Signs of layering in concrete were noted

Table 5

Density, UPV(*) and Splitting Tensile Strength(**) of
150 mm diameter Cores from the RCC Trial Test Pads of Various Mixes

Pad No.	Age In Months	Mix 1 Density(+) kg/m^3	Mix 1 UPV m/s	Mix 1 Split. Tensil Strength MPa	Mix 2 Density(+) kg/m^3	Mix 2 UPV m/s	Mix 2 Split. Tensil Strength MPa	Mix 3 Density(+) kg/m^3	Mix 3 UPV m/s	Mix 3 Split. Tensil Strength MPa
1	6	2380	4300	1.9	-	-	-	-	-	-
		2430	4450	3.3	-	-	-	-	-	-
2	6	2460	4420	2.9	-	-	-	-	-	-
		2450	4420	2.9	-	-	-	-	-	-
3	6	2460	4360	2.7	2470	4640	2.8	2430	4280	2.3
		2470	4360	3.2	2470	4320	3.3	2450	4010	2.3
	12	2480	4720	3.8	2460	4840	3.0	2450	4360	3.1
		-	-	-	2480	4560	3.4	2450	4370	3.3

(CV13)

(*) UPV: Ultrasonic Pulse Velocity (m/s)

(**) Tested according to ASTM C 496 method

(+) Determined, based on weights in air and in water at room temperature

Table 6

Apparent Density, Absorption, Volume of Voids (*)
of 150 mm Diameter Cores from the RCC Trial Test Pads of Various Mixes

		MIX 1				MIX 2				MIX 3			
Pad No.	Age In Mth	Absorption 24h %	Absorption 5h Boiling %	Apparent Density kg/m^3	Volume Of Voids %	Absorption 24h %	Absorption 5h Boiling %	Apparent Density kg/m^3	Volume Of Voids %	Absorption 24h %	Absorption 5h Boiling %	Apparent Density kg/m^3	Volume Of Voids %
1	6	5.2	5.3	2640	12.3	5.8	8.2	2690	18.2	5.8	6.7	2680	15.3
2	6	4.8	6.2	2690	14.3	4.9	5.8	2680	13.4	5.8	6.2	2680	14.2
3	6	4.2	4.4	2665	10.5	4.9	5.5	2690	13.0	5.8	6.2	2675	14.4

(*) Determined by ASTM C 642 method.

(CV13)

Table 7
Permeability by Chloride-Ion Diffusion Test, Measured in Coulombs on Concrete Discs (+) from 150 mm Diameter Cores from the RCC Trial Test Pads of Various Mixes.

Pad No.	Age In Months	Mix 1		Mix 2		Mix 3		REMARKS	
		Away From Joint	At a Joint	Away From Joint	At a Joint	Away From Joint	At a Joint	Interpretation of data (*):	
								Rating	Coulombs
1	6	3656	6455 (**)	-	4140	-	1850	High	4000
		2934		3324		821		Moderate	2000 to 4000
2	6		-		-		-		
		3583						Low	1000 to 2000
								Very low	100 to 1000
3	6	4336	-	-	-	-	-		
								Negligible	100

(+) All tests were done on 100 mm diameter, 60 mm thick concrete discs obtained at right angle to the axis of the original 150 mm diameter cores.

(*) According to PCA procedure using a Test Set Model 164, manufactured by RLC Instrument Co.

(**) One-day old joint with mortar.
Other joints were placed within the same day without mortar.

(CV13)

Table 8
Shear Strength Test Results on Specimens
Cut from RCC Cores.

Sample From Pad 1 (see Figure 1)	Shear Strength Of Specimens(*) With a Normal Stress of 1.7 MPa (MPa)	
	At Joint(**)	Away from Joint
Mix 1	4.4(+)	5.1
Mix 2	5.0	5.2
Mix 3	4.9	4.9

(*) The test specimens "At Joint" and "Away from Joint" were made from the same core.

(**) The joint was between two lifts, placed a day apart.

(+) The specimen was loaded earlier without failure at a normal stress of 3.4 MPa.

Note: An apparatus capable of applying horizontal forces with a confining normal force was used (see Figure 6)

(CV13)

Table 9
Rapid Freeze-Thaw (F/T) Test in Water
of RCC Specimen(+) Cut from a 150 mm Diameter
Core Containing the One-Day Old Joint of Mix 1, Pad 1 (see Figure 1)

F/T Cycles	Ultrasonic Pulse Velocity (m/s)		Modulus (% of initial)	Change in Weight %		Remarks
0	4020		100.0	nil		a) Between 44 and 64 cycles, the prism broke into two pieces, at the joint. (1) 210 x 100 x 75 mm and (2) 188 x 100 x 75 mm
20	-		81.0	+0.28		
44	-		64.0	+0.18		
64	Broke into two pieces(1&2): no further tests for Modulus			-0.09		
	(1) 210x100x75mm	(2) 188x100x75mm		(1)	(2)	b) The test was continued with measurements taken on two pieces separately, except that dynamic modulus test was discontinued.
64	4000	4050	no test	-	-	
74	3860	3970	no test	-0.13	-0.03	
104	3720	3970	no test	-0.90	-0.47	
121	3370	3810	no test	-2.06	-1.16	
146	(*)	3890	no test	-9.56	-3.16	
165	-	3740	no test	-13.15	-4.29	
	The pieces were saturated in water overnight & sealed in plastic bags without water					c) The pieces were immersed in water up to 165 cycles of F/T. After that they were sealed in plastic bags without water to prevent moisture loss during the remaining F/T cycles. Therefore, the remaining F/T cycles were carried out under saturated conditions without immersion in water.
191	no test	3810	no test	-13.9	-4.54	
228	no test	3740	no test	-15.13	-5.12	
252	no test	3340	no test	-15.86	-5.34	
288	no test	3460	no test	-17.49	-6.59	
320	no test	3400	no test	-18.56	-7.65	
357	no test	3340	no test	-20.17	-8.06	
382	no test	2800	no test	-21.60	-8.47	
414	no test	2760	no test	-22.28	-8.83	
451	no test	3340	no test	-22.60	-9.11	
465	no test	2980	no test	-23.23	-9.25	

(+) The specimen size: 400 x 100 x 75 mm.
(*) Test discontinued because of uneven contact surface

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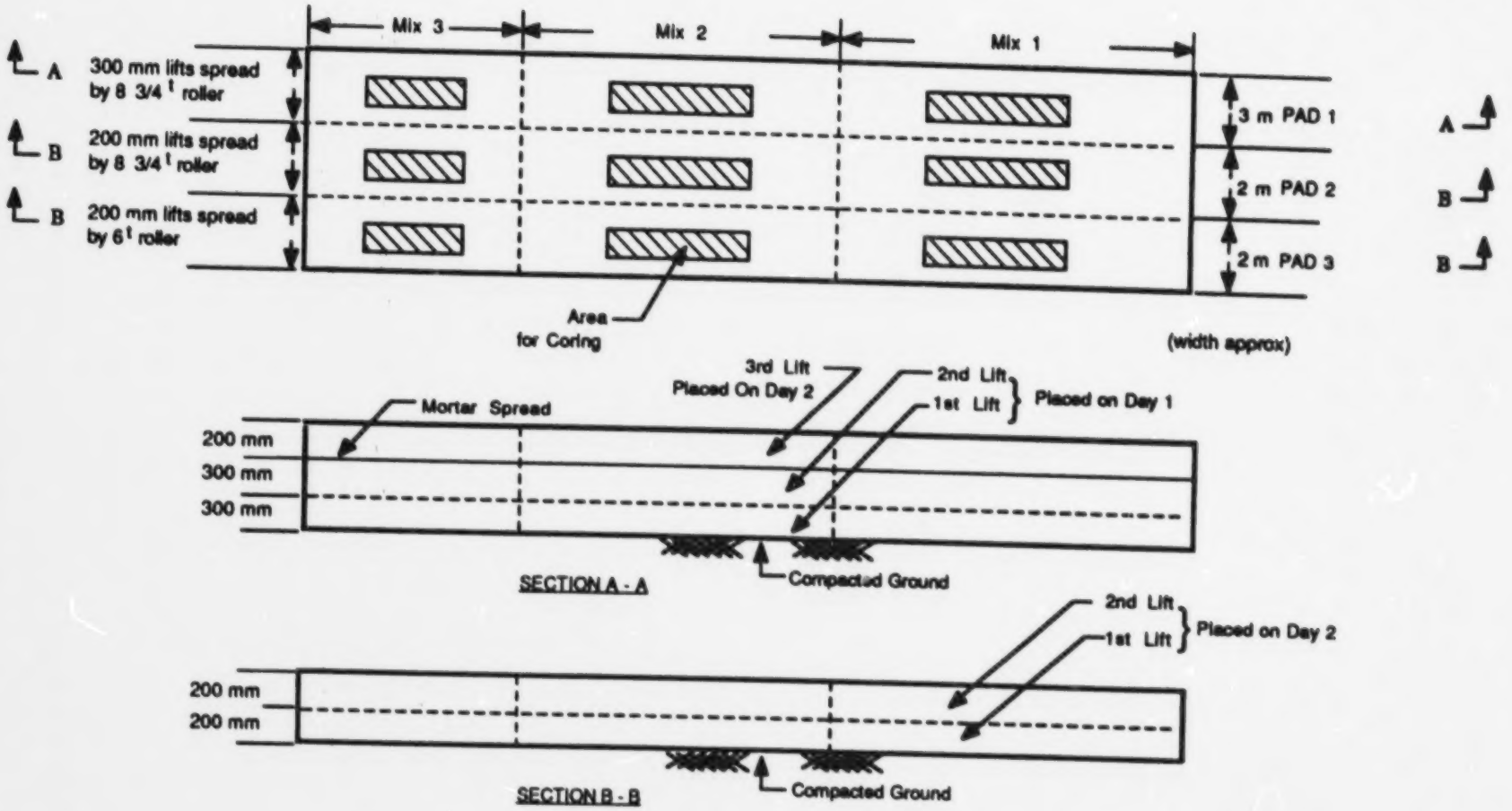

FIGURE 1

LAYOUT OF ROLLER-COMPACTED CONCRETE FIELD TRIAL

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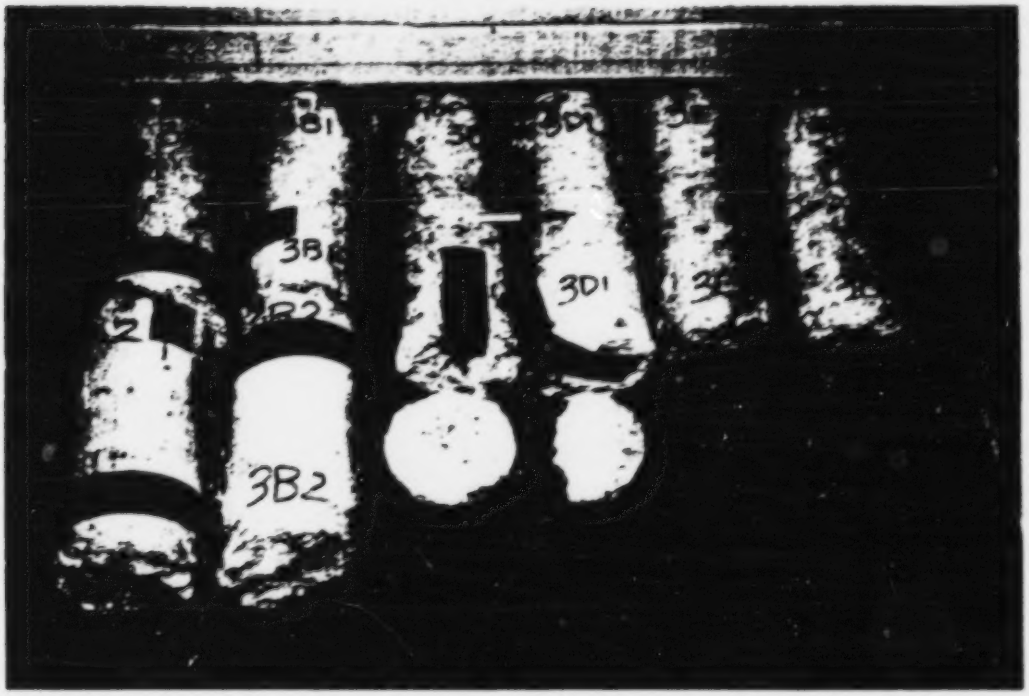


Figure 2
Some of the 150 mm dia. cores, recovered from the RCC trial pads, shown wrapped in plastic sheets.

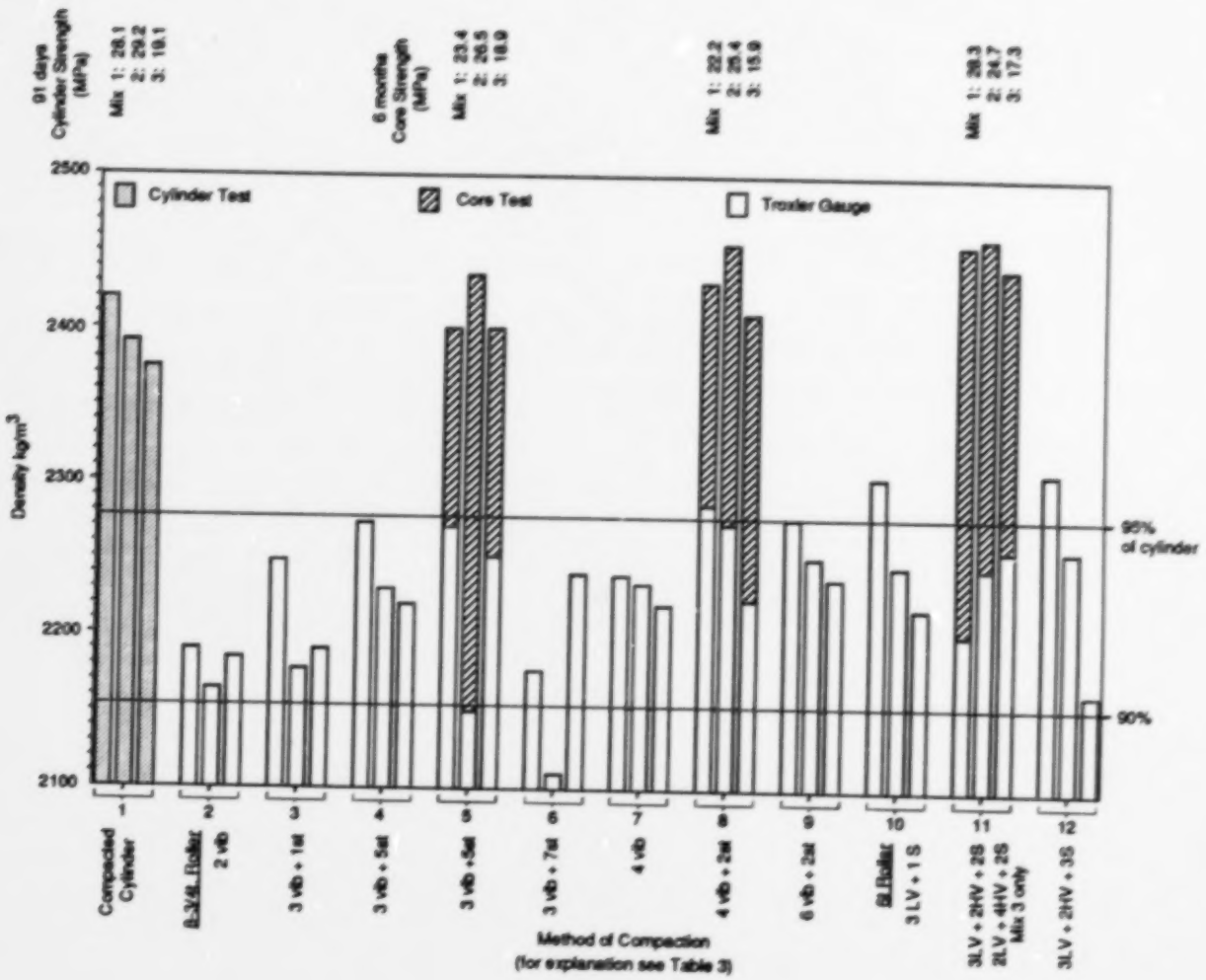


FIGURE 3
A SUMMARY OF IN-PLACE DENSITY TESTS BY TROXLER GAUGE AND COMPARISON WITH THOSE OF CORES AND CYLINDERS

Figure 4
RCC Cores tested for compressive strength, Mix 1, pad 1.

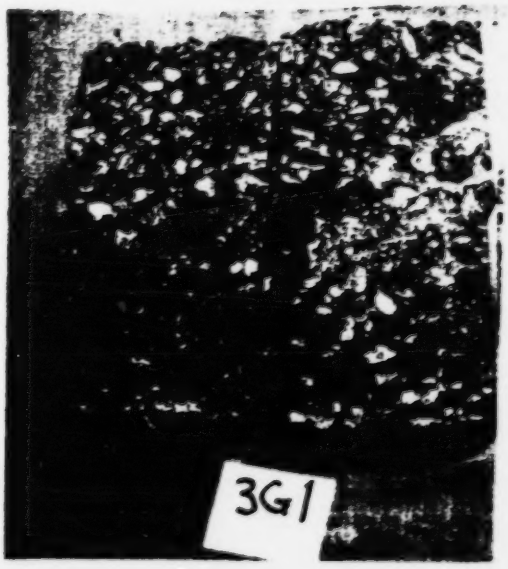


Figure 5
RCC Cores tested for splitting tensile strength, Mix 3, pad 3. Note the good failure pattern. The specimen also cracked at the joint during testing; horizontal separation is seen at the upper portion of the specimen.

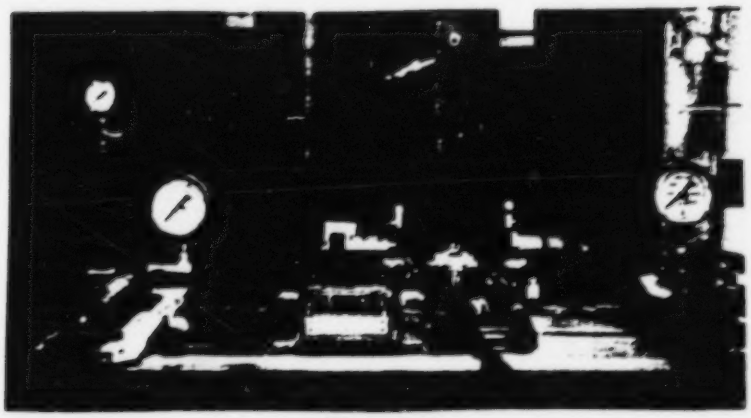
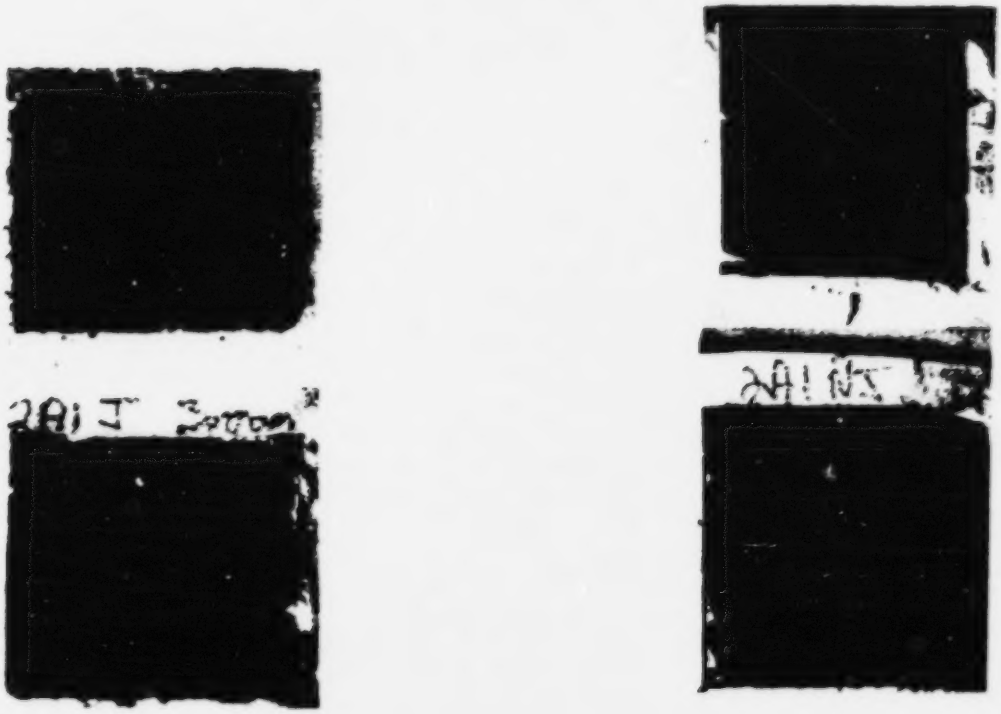


Figure 6
Shear Test Apparatus. A 150 x 150 mm concrete specimen is sheared by a horizontal force, while confined at the base and subjected to a constant normal force.



(A) (B)

Figure 7
Condition of the surface of specimens (150 mm x 150 mm) after failure under shear force at a normal stress of 1.7 MPa
(A): without joint, (B): at a day-old joint,
The specimen is from Mix 2, pad 1.

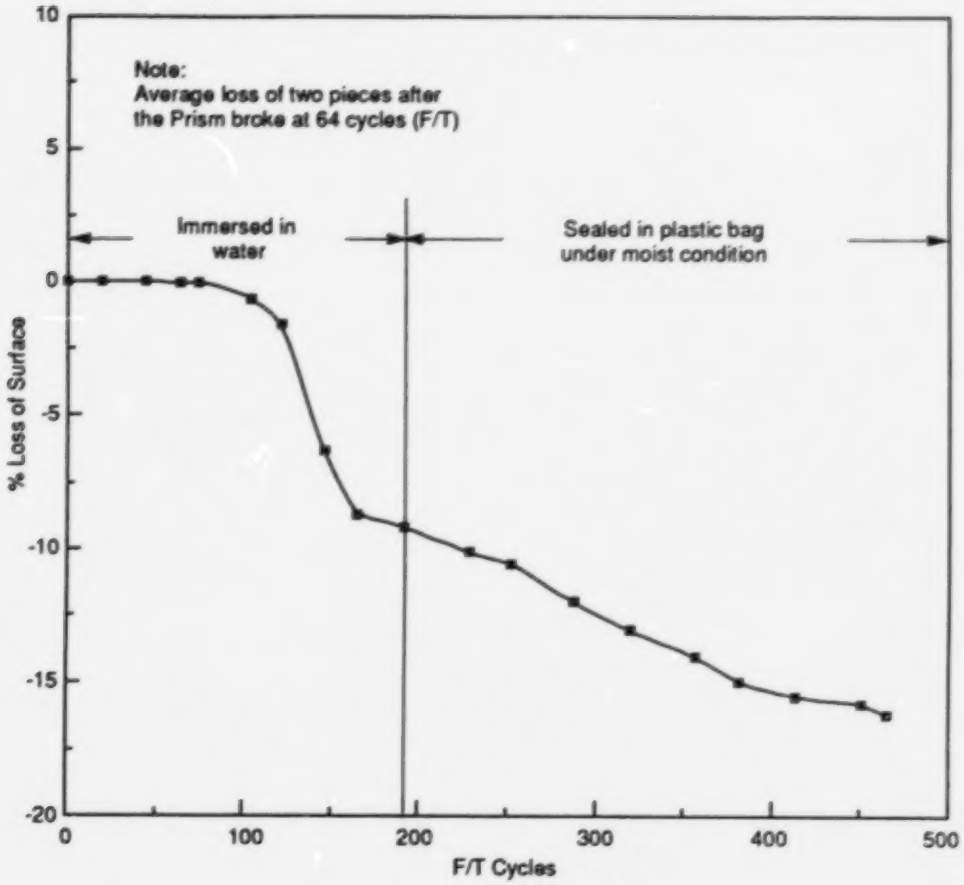


FIGURE 8

PERCENT LOSS OF SURFACE MATERIAL OF A RCC PRISM (400 x 100 x 75 mm) DUE TO FREEZE-THAW (F/T) CYCLES IN WATER AND LATER UNDER MOIST CONDITION (See Table 9)

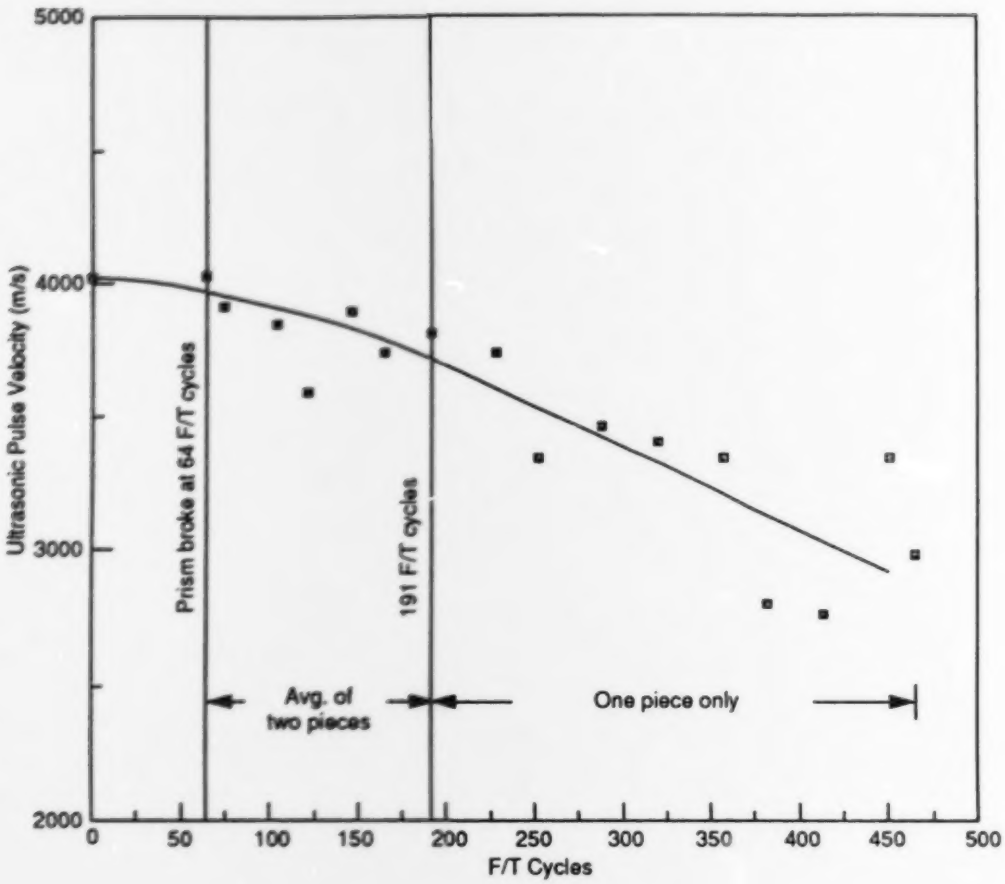


FIGURE 9

CHANGE IN ULTRASONIC PULSE VELOCITY THROUGH A RCC- PRISM (400 x 100 x 75 mm) DUE TO FREEZE-THAW (F/T) CYCLES. AVERAGE OF TWO PIECES HAVE BEEN PLOTTED AFTER THE PRISM BROKE AT 64 CYCLES. ALSO, BEYOND 191 CYCLES, MEASUREMENT ON ONLY ONE PIECE WAS TAKEN. (See Table 9)